Connecting the Visible to the Invisible: Helping Middle School Students Understand Complex Ecosystem Processes

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Abstract

Learning about ecosystems is challenging because, like any complex system, they are simultaneously multidimensional and dynamic. Often, learners engage only with the visible components of an ecosystem and draw either single or linear causal connections between components. In this study, we explored how using a Structure-Behavior-Function framework supported middle school students' conceptual and complex reasoning about the visible and invisible components of an ecosystem. Research shows that learners often engage only with the visible components of an ecosystem and draw linear/single causal connections between the components of the ecosystem. Our findings suggest that a combination of using structure, behavior, and function approach along with a set of carefully designed technology tools can push the students toward a better understanding of the ecosystem functioning. The results show that along with the visible components of the ecosystem, students have started to identify the invisible components of the ecosystem.

Keywords: Ecosystems learning, SBF, complex systems, Science education

Introduction

Given the urgent need to empower the future generation with knowledge to help them make informed decisions about their ecosystems and environment, both national and local science standards have a growing focus on ecosystems learning (e.g., National Research Council, 1996; New Jersey Department of Education, 2006). Developing ecosystems understanding is challenging, because it requires learners to understand how different aspects of an ecosystem are interconnected, and the processes that occur within such systems (Anderson, 2008; Covitt & Gunckel, 2008; Jordan et al., 2009).

Ecosystem processes are challenging for learners, because these are complex systems that transcend spatial, temporal and cognitive boundaries (Pickett, et al 1997). Similar to other complex systems, ecosystems are also characterized by multidimensional processes that connect visible and invisible components of the system to one another (Hmelo-Silver & Azevedo, 2006). These visible and invisible components within the ecosystem are interdependent. The components have their own behavior patterns and any change in the patterns, affects not only other components, but also overall functioning of the system (Jordan, et al 2009). The dynamic and multifaceted nature of an ecosystem makes it difficult for learners to grasp the associations and interactions among system components (Gallegos et al 1994).

Learners find it challenging to think beyond the linear relationships and visible components of an ecosystem (e.g., food chains: Reiner & Eilam, 2001; aquaria: Hmelo-Silver, Marathe, & Liu, 2007; systems: Hogan, 2000, food webs/nutrient cycles: Hogan & Fisherkeller, 1996, energy flow: Leach et al. 1996; water cycle: Covitt & Gunkel, 2008). When asked to draw or name components of an ecosystem, learners often focus on the visible components of the ecosystem (Gellert, 1962; Hmelo, Holton, & Kolodner, 2000). Expert-novice studies suggest that that it is hard for young learners to conceptualize the invisible components within an ecosystem such as: oxygen, nitrogen, and bacteria, (Hmelo-Silver, Marathe, & Liu, 2007). It is also challenging for students to think beyond single causality and linear connections between ecosystem components (Grotzer & Basca 2003).

In this paper, we present the results of a technology-intensive classroom intervention designed to teach middle schools students about aquatic ecosystems. The goals of our intervention are to help learners develop deep understanding of ecosystems and to use tools that make the invisible visible and the interconnections explicit.

Aquariums as Models for Learning

To help students understand complex systems, we implemented a two-week aquarium unit that was designed by a team of learning scientists, middle school classroom teachers, and ecologists. The technology consisted of a suite of tools: a function-oriented hypermedia (Liu & Hmelo-Silver, 2009), simulations of macro- and micro-level processes (Liu & Hmelo-Silver, 2008; Gray et al. 2008), and the Aquarium Construction Kit (ACT; Goel, Rugaber, & Vattam, 2009). The unit was grounded in the structure behavior and function approach.

Our approach to instruction is grounded in the structure-behavior-function theory (Goel et al., 2009). The structure behavior function (SBF) approach is useful to explain dynamic systems with multiple components and levels (Goel et al., 2009; Liu & Hmelo-Silver, 2009). We view SBF theory as providing a conceptual representation with canonical explanations in biological systems, as well as, being consistent with expert understanding (Bechtel & Abrahamson, 2005; Hmelo-Silver et al., 2007). In addition to helping students organize their system knowledge the SBF representation also provides a scaffold for overall knowledge organization. The approach helps the learner to breakdown and distinguish individual parts of the complex system.

In a biological system, structure refers to components of an ecosystem that have form. Structures can be macro (e.g Fish, plants) or micro (e.g bacteria, fungi) in nature. Behavior represents the process of how structures achieve their functions, and, finally, functions are roles the structures play in an ecosystem.

Technology Support for Learning about Complex System

It is difficult for learners to understand many aspects of ecosystems because they have not had opportunities to engage with those processes that are dynamic and outside their perceptual understanding. In addition to helping students organize their system knowledge, the SBF representation also provides a scaffold for overall knowledge organization because it helps learners consider the relationships among form and function as well as the causal behaviors. We make SBF explicit through the use of hypermedia, organized in terms of SBF, and through the Aquarium Construction Toolkit (ACT) (Figure 1a and 1b).

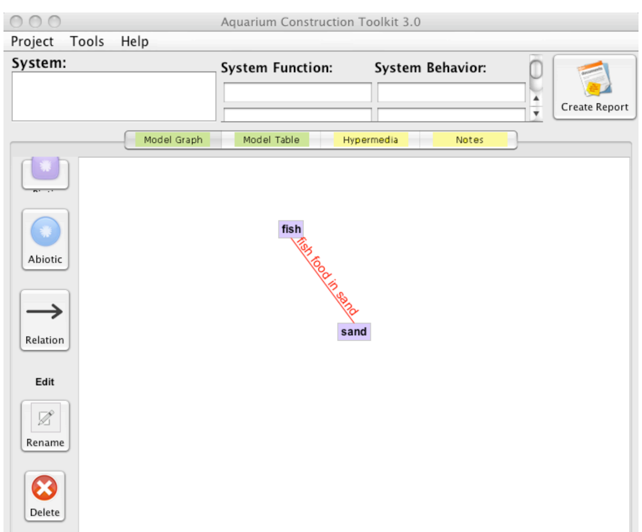

Figure 1a. ACT: A space to create models

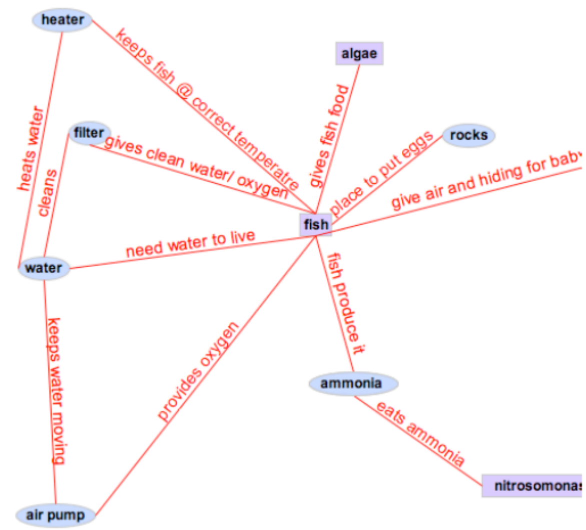

Figure 1b. ACT: Example of model created by a student.

Figure 2. SBF is used to organize the hypermedia

Along with the hypermedia and ACT tools students also used NetLogo simulations to learn about behaviors and functions within an ecosystem (Wilensky & Reisman, 2006). Using these simulations, (Figure 3) students learned about how to keep an ecosystem 'healthy.' For example, the macro fishspawn simulation allowed students to manipulate different aspects of the ecosystem such as initial population, spawning, filtrations, and amount of food. Thus if the students overfed the fish then the increasing ammonia (due to fish waste) within the water would affect water quality and the fish would die. This helps problematize water quality, which is a black box in the macro simulation. This creates the need for students to identify some of the invisible components within an ecosystem, and students also start to see the importance of these invisible components. For example, the students can observe how crucial nitrification cycle is for the overall health of an ecosystem. They also can learn that many components of the ecosystem involved in the nitrification process are invisible. These behaviors and functions can then be observed in the micro level simulation.

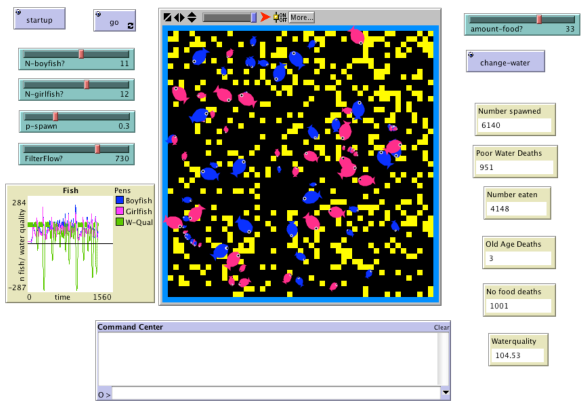

Figure 3: NetLogo simulation

Classroom Instruction

The science teacher introduced the unit by asking students to articulate their thoughts about ecosystems functions. This allowed the teacher to gauge the students' prior knowledge. The teacher then moved on to the ACT modeling tool and asked the students to represent their thoughts about ecosystems as structures behaviors and functions. The students recorded their ideas in a table within the ACT tool (Figure 4).

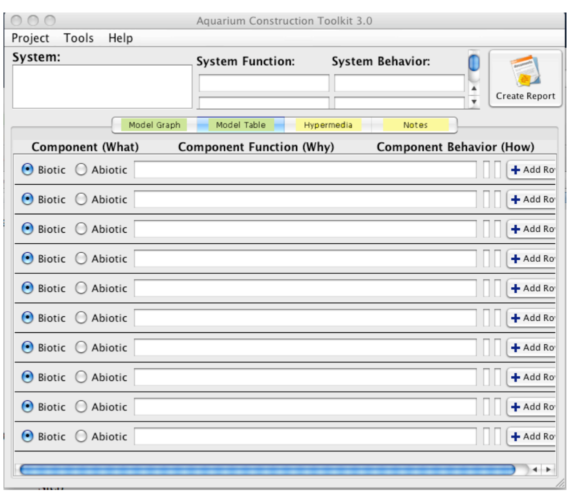

Figure 4: ACT table where students record ideas as structure, behavior, and function

The teacher also encouraged the students to use the hypermedia to sharpen their existing ideas about the ecosystems. The teacher then proceeded to the modeling activity using NetLogo simulations. In the NetLogo simulations students manipulated various ecosystem components (number of fish, amount of food, etc) in order to maintain a healthy ecosystem. The students worked in groups and were given the freedom to continuously refine their models. Finally at the end of the two-week period the students presented their models in front of the entire classroom.

Methods

Participants

Fifty-four seventh grade students from a suburban public middle school in the northeast United States participated in this study during their regular science instruction time. Two of the participants reported having an aquarium at home and most had been to a public aquarium. Many had also been on excursions to the beach or on fishing trips with adults in their families.

Data Sources

The students were given pre and post-tests before and after the intervention. In the pre and post-test students were asked to draw components of an aquatic ecosystem, and show relationships between them. They were also asked to label all of the components and relationships between those components.

Coding for pre and post tests

There were three parts to the coding. The first part of the coding scheme involved counting the number of visible and invisible ecosystem components that were drawn by the students. The second part of the coding scheme involved counting the number of relationships that the students observed between the components in their drawing. Care was taken to make sure that the relationships were scientifically plausible. We coded the connections on a three-point scale. We gave a connection one point if students made implausible connections between components of the ecosystem. A connection was assigned two points if students made plausible connections within the same level of an ecosystem (e,g. visible component to visible component; invisibile to invisible). One example of this is a connection that shows fish eat plants. Here both fish and plants are visible components of the ecosystem. A connection was assigned three points if students were able to make plausible connections between the visible and invisible components of the ecosystem. An example of this would be a connection showing that fish breathe oxygen (Figure 5). Here fish is the visible component of the ecosystem and oxygen is the invisible component of the ecosystem.

The third part of the coding scheme was designed to find out the type of connections the students made between the different components of the ecosystem. As components within an ecosystem function nonlinearly, it was important to find out whether student understanding of ecosystem functioning went beyond linear-single cause relationships. The coding scheme for the third part (types of connections) was adapted from Grotzer & Basca (2003).

This part of the coding scheme was also coded on a three-point scale. A connection was assigned a point if students made a 'simple linear' connection between the components of the ecosystem. A simple linear connection was observed as a connection that was linear, one directional and indicating single cause and effect. For example, fish eat plants is a linear connection because it indicates that only fish benefit from the plants. A connection was given two points if the students made a 'complex linear' connection between the components of the ecosystem.

A complex linear connection was defined as a linear connection that had more than one cause and effect. For example, plants get energy from the sun, fish eat plants and thus fish get energy from the plants is a complex linear relationship because it shows one directional relationship between more than two components of the ecosystem. This code was also used when students represented symbiotic relationships/mutually beneficial relationships.

Finally a connection was given three points if the connection was observed to connect more than two components in a mutually benefiting relationship. The connection was called 'cyclic' (Figure 5). For example, fish waste produces ammonia, a form of nitrogen that is then transformed by different bacteria into new forms of nitrogen that support plant growth, which in turn benefit the fish.

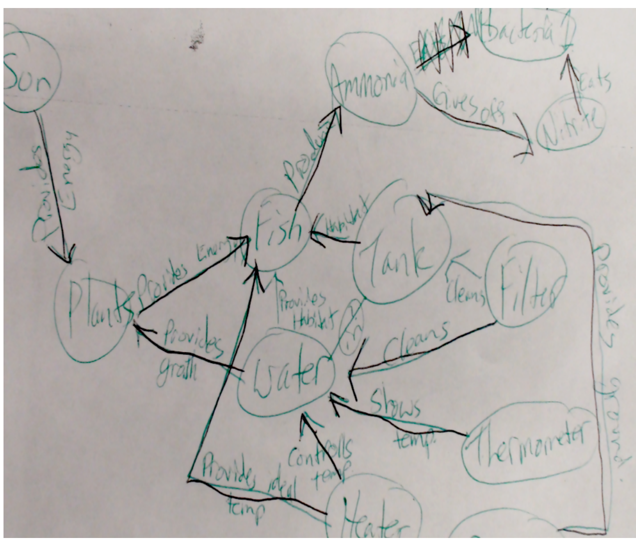

Figure 5: Connecting the visible (fish) to invisible (ammonia). Also, an example of a cyclic connection.

Reliability was calculated by having three independent raters code the entire sample. The overall reliability was 98% agreement.

Results

We expected the students to start identifying invisible components within an ecosystem. Since the intervention provided them with an opportunity to learn about the system in depth the results show that the students have identified more invisible components (Table 1). However, the students did not show any significant change in identifying the visible components (Table 1).

Table 1: Components coding (*N*=54).

	Visible	Invisible
Pretest Mean (SD)	8.50 (3.34)	0.28 (0.49)
Posttest Mean (SD)	7.61 (3.21)	2.87 (2.17)
Sample Size	54	54
T (53)	1.90	8.86*
Effect Size	0.13	0.64

*$p < 0.05$

We also expected the students to make more plausible connections between the components because the instruction was designed to scaffold students' understanding of how ecosystem components are connected to each other. The results, shown in Table 2, demonstrate that students made significant progress in making plausible connections within levels (visible to visible and invisible to invisible) and between levels (visible to invisible).

Table 2: Plausible connections made between ecosystems components (N=54)

	Plausible connections made within level	Plausible connections made between levels:
Pretest Mean (SD)	3.81 (2.15)	0.17 (0.61)
Posttest Mean (SD)	4.87 (2.91)	1.43 (1.53)
Sample Size	54	54
T (53)	2.55*	7.09*
Effect Size	0.21	0.47

*$p < 0.05$

Finally we investigated whether the types of plausible connections students were making were demonstrating the complexity of ecosystem functions. It was not clear whether students were able to move beyond making linear connections or complex linear connections. We found that the number of students making simple linear connections increased from pre to post. However, there was no significant change in the number of students making complex linear connections. Finally there was a significant change in the number of students making cyclic connections. Although, the results clearly showed that only a small number of students made a leap to making more complex connections between the ecosystem components (Table 3).

Table 3: Types of connections made by students

	Linear Relationships	Linear Complex relationships	Cyclic
Pretest Mean (SD)	1.85 (1.87)	0.52 (0.91)	0.02 (0.14)
Posttest Mean (SD)	2.80 (2.33)	0.74 (0.96)	0.15 (0.36)
T (53)	2.76*	1.73	2.81*
Effect Size	0.21	0.11	0.09

*$p < 0.05$

Discussion and Conclusion

Our results show that students find it challenging to conceptualize the role of invisible components within an ecosystem. Consistent with other research, students initially focus on the interactions between the visible components of the ecosystem (e.g., Hmelo-Silver et al., 2007). For example, most students represented the fish eating fish (prey predator) relationship as the primary relationship within an ecosystem. However the study also shows that students are on a trajectory of conceptual change and began to consider invisible components of the ecosystem and how they connect to what is visible.

Our findings suggest that a combination of using structure, behavior, and function approach along with a set of carefully designed technology tools can push the students toward a better understanding of the ecosystem. Another study (Goel et al. 2010) that looks at how the ACT tool helps students construct SBF models of complex ecosystem processes is a part of the proceedings.

The results show that along with the visible components of the ecosystem, students have started to identify the invisible components of the ecosystem. They are still not completely making a sophisticated model that includes the visible and invisible components connected to each other, but this is the first step. Moving students to a more robust and rich understanding of complex systems requires more than a two week intervention. In our ongoing research, we are exploring how SBF thinking can provide a tool for students to understand complex biological systems that are pervasive in the world in which they live and are key components of helping students become scientifically and environmentally literate citizens.

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